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Incorporation of the Kinetic Chain Into Shoulder-Elevation Exercises: Does It Affect Scapular Muscle Activity?

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Context: Scapular rehabilitation exercises should focus on selective activation of weaker muscles and minimal activation of hyperactive muscles. For rehabilitation of overhead athletes, single-plane open chain exercises below 90° of shoulder elevation are often recommended. Moreover, incorporating the kinetic chain in shoulder rehabilitation exercises is advised and has been suggested to influence scapular muscle activity levels.

Objective: To study the influence of kinetic chain incorporation during 5 variations of a shoulder-elevation exercise on scapular muscle activity.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: Thirty-one asymptomatic participants (15 men, 16 women).

Main Outcome Measure(s): The electromyographic activity of the upper (UT), middle (MT), and lower (LT) trapezius, and serratus anterior was determined during 5 variations of bilateral elevation with external rotation: (1) open-hand position (reference exercise), (2) closed-hand position, (3) dynamic bipedal squat, (4) static unipedal squat, and (5) dynamic unipedal squat on the contralateral leg. All data were normalized as a percentage of maximal voluntary isometric contraction (MVIC).

Results: A closed-hand position (exercise 2) instead of an open-hand position (exercise 1) resulted in lower MT (mean difference = 3.44% MVIC) and LT (mean difference = 7.76% MVIC) activity. Incorporating the lower limb (exercises 3–5) increased UT activity when compared with exercise 1 (mean differences = 3.67, 2.68, 5.02% MVIC, respectively), which in general resulted in increased UT : MT ratios. Additionally, LT activity decreased when a dynamic unipedal squat was added (mean difference: 4.90% MVIC). For the serratus anterior, the greatest activity occurred during elevation in a static unipedal squat position (exercise 4, 22.90% MVIC).

Conclusions: Incorporating the kinetic chain during shoulder-elevation exercises influenced scapular muscle activity and ratios. In particular, incorporating the lower limb resulted in more UT activity, whereas the open-hand position increased MT and LT activity.

Key Words: electromyography, scapula, trapezius, exercise therapy

Key Points

- Activity of the middle and lower trapezius increased when the exercise was performed with an open instead of a closed hand.
- Activity of the upper trapezius increased when the lower limbs were incorporated.
- Incorporating the kinetic chain during shoulder-elevation exercises is not recommended for scapular muscle balance but could be useful with more complex kinetic chain exercise variations.

The scapula plays an important role in the athlete's shoulder function during an overhead throw. As a link between the trunk and the arm, the scapula transfers and increases energy from the lower limb and trunk to the rapidly throwing arm.[1] Therefore, scapular dysfunction might contribute to the pathogeneses of shoulder injuries in the throwing athlete.[2,3] More specifically, abnormalities in scapular position or dynamic motion (ie, scapular dyskinesis) are linked with a variety of shoulder conditions such as impingement, rotator cuff disorders, labral injuries, and instability.[1,2] Strength deficits or imbalances of the scapular muscles are demonstrated by scapular dyskinesis[2–4] and are often related to a combination of hypoactive and hyperactive muscles.[4–6] Therefore, the rehabilitation of overhead athletes should focus on scapular muscle balance training with selective activation of weaker muscles combined with minimal activity in hyperactive muscles[4] so that the scapula can regain its function as a stable base of support for the humerus during an overhead throw.

As a part of the rehabilitation for overhead athletes, authors[7] of a recent systematic review recommended single-plane open chain exercises below 90° of shoulder elevation, including elastic resistance. For optimal scapular muscle balance, adding an elastic resistance to external rotation during an elevation exercise has been proven beneficial as it increases middle (MT) and lower (LT) trapezius activity.[8] Additionally, clinical experts advise incorporating the kinetic chain into shoulder rehabilitation exercises[7,9,10] because upper extremity performance does not depend on a single shoulder-joint movement but rather on sequenced activation of the lower to the upper kinetic chain.[2,3,7] Moreover, scapular muscle activity is influenced by incorporating the kinetic chain into shoulder exercises.[11–15] De Mey et al[11] investigated the effects of lower limb position and movement on upper trapezius (UT) and LT activity during scapular-retraction variations. Overall trapezius activity was greater when standing in a squat position on the contralateral leg compared with the conventional seated performance of the exercise. However, the influence of incorporating the kinetic chain during a more functional shoulder-elevation exercise and the effect on scapular muscle activity, including the serratus anterior (SA) muscle, has not yet been examined. Therefore, the first aim of our study was to determine whether adding kinetic chain variations to a bilateral elevation with external rotation affected scapular muscle activity. We hypothesized that kinetic chain incorporation would change activity in all of the scapular muscles. Secondly, we examined differences in the intramuscular balance of the UT : MT, UT : LT, and UT : SA during the selected exercises.

METHODS

Participants

Thirty-one participants (15 men, 16 women) volunteered for this study (age = 22.5 ± 1.33 years, height = 175.1 ± 7.12 m, weight = 66.4 ± 9.22 kg, body mass index = 21.6 ± 2.17 kg/m^2). All participants were free from pain in the upper limb, lower limb, and spine during the 6 months before testing, were in good general health, and had no history of fracture or orthopaedic surgery. They did not perform overhead sports or upper limb strength training for more than 6 hours per week. Written informed consent was acquired from all participants, and this study was approved by the Ethical Committee of Ghent University Hospital, Belgium.

Instrumentation

The skin surface was shaved with a disposable razor, scrubbed using a cotton ball with scrubbing gel, and then cleaned with a cotton ball soaked in alcohol to reduce impedance. Self-adhesive circular bipolar surface electrodes (Ag/AgCl; model BlueSensor P, REF P-00-S/50, 40.8 × 34 mm; Ambu Inc, Ballerup, Denmark) were placed over the SA and the 3 parts of the trapezius muscle on the dominant side. *Arm dominance* was determined as the arm used to throw a ball. Recommendations for surface electromyography (EMG)[16] in the noninvasive assessment of muscles were followed for electrode placement and interelectrode distance. All electrodes were placed over the muscle bellies in line with the orientation of the muscle fibers. A reference electrode was placed over the ipsilateral clavicle. To ensure consistency, the same investigator was responsible for all electrode placements. The electrodes were connected to a 16-channel EMG receiver (model Myosystem 2000; Noraxon USA Inc, Scottsdale, AZ). The sampling rate was 1000 Hz, and all raw myoelectric signals were preamplified (overall gain = 1000, common rate rejection ratio = 115 dB, signal-to-noise ratio <1 μV root mean square baseline noise). Before testing, we verified correct electrode placement and quality of the EMG signal through visual inspection of the signal during muscle-specific movements. Additionally, a high-speed camera (model OptiTrack Flex 3; NaturalPoint, Inc, Corvallis, OR; 100 frames per second) was used to track the direction of motion during all exercises for the purpose of automatically and more precisely marking the start and end of each exercise repetition during the analysis. Two reflective markers were applied on the lateral side of the dominant upper arm with double-sided adhesive tape. The markers were placed 5 cm distal to the middle acromion and 5 cm proximal to the lateral humeral epicondyle. The camera was positioned perpendicular to these reflective markers.

Procedures

First, maximal voluntary isometric contractions (MVICs) for the SA, UT, MT, and LT were quantified for normalization. The MVICs were measured in randomized order, and resistance was always applied just proximal to the elbow to prevent further upward movement.[17] Four tests were performed: participants were seated with the arms fully extended (1) in 135° of forward flexion or (2) in 90° of shoulder abduction or participants lay prone with the arm fully extended (3) in external rotation (thumb up) and in 90° of horizontal abduction or (4) in 145° of abduction. For each scapular muscle, the highest activity level generated across the standard set of 4 positions was used for normalization.[17] The same investigator was responsible for all MVIC measurements to ensure test consistency. Participants were instructed in this procedure and allowed to practice. Test execution was corrected by the investigator when necessary. Afterward, participants performed 3 trials of a 5-second isometric contraction separated by 15 seconds of rest. They were asked to exert maximal effort in 2 seconds and sustain it for 5 seconds. The investigator counted the seconds out loud (controlled by a metronome) and orally encouraged the participants to perform a maximal-effort MVIC. Between MVIC measurements of different muscles, 15 seconds of rest were provided.[18]

Second, participants randomly performed 5 variations of bilateral elevation with external rotation: (1) open-hand position as reference exercise, (2) closed-hand (ie, making a fist) position, (3) dynamic bipedal squat, (4) static unipedal squat on the contralateral leg, and (5) dynamic unipedal squat on the contralateral leg (see Figure A through E and Table 1 for exercise descriptions). Comparison of exercises 1 and 2 will be referred to as "altering upper extremity position," while comparison of exercises 1 and 3 through 5 is described as "incorporation of the lower extremity." For the dynamic movement variations (exercises 3 and 5), participants extended the legs while elevating the arms. Apart from exercise 2, all exercises were performed with an open-hand position. The quality of the exercise performance was checked and corrected by the examiner so that all exercises were executed correctly and in a standardized way. Five repetitions of each exercise were completed, and each repetition consisted of a 3-second elevation and 3-second lowering phase. Between exercises, a 4-minute rest period was provided. A metronome was used to ensure the correct MVIC or exercise speed (60 beeps/min). Resistance to external rotation during the exercise was supplied by an elastic band of standardized length across participants. The color of the elastic band was determined in a pilot study (n = 24) and based on sex and body weight.[18,19]

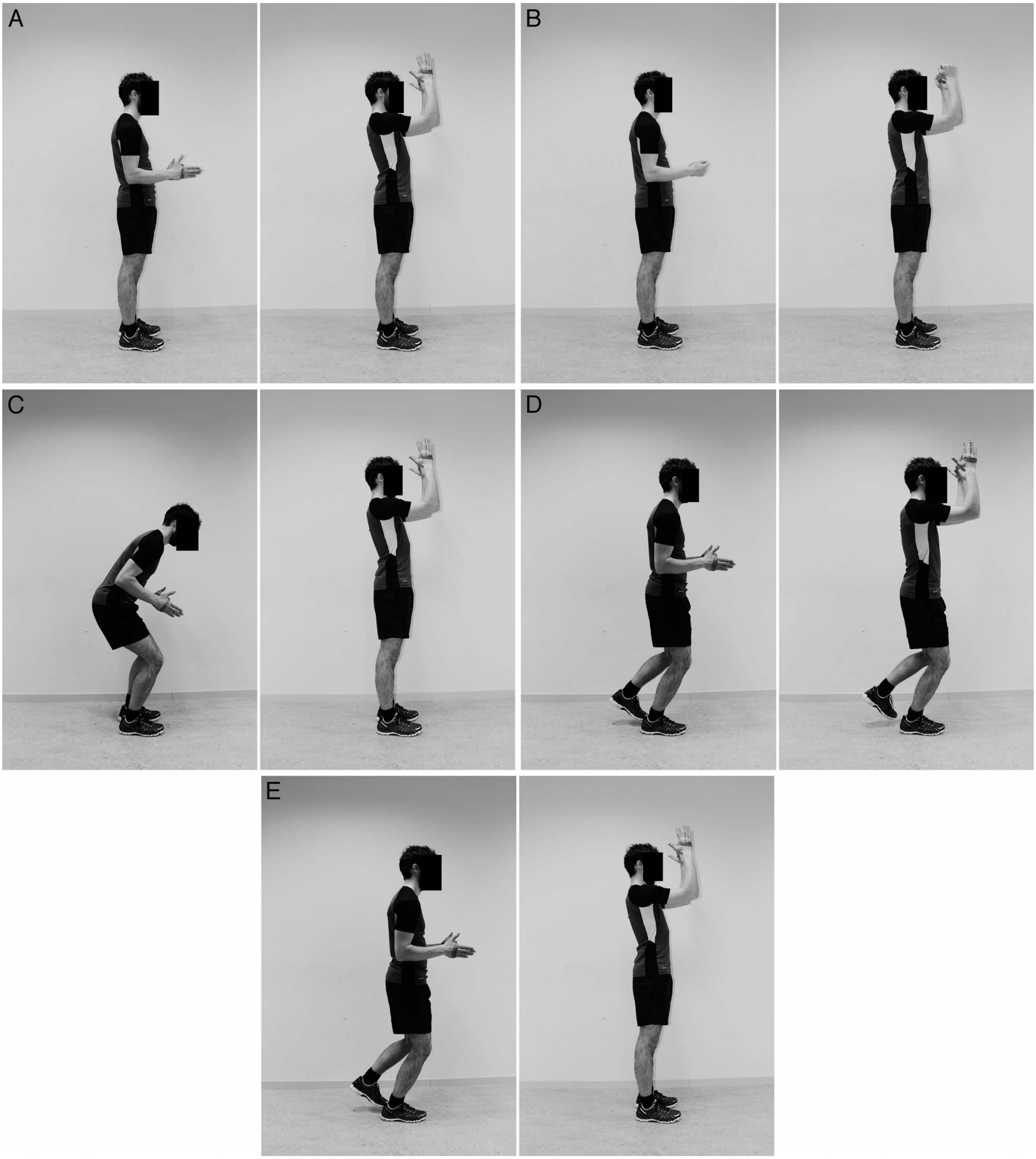

Figure. Five variations of bilateral elevation with external rotation. A, exercise 1: open hand. B, exercise 2: closed hand. C, exercise 3: dynamic bipedal squat. D, exercise 4: static unipedal squat. E, exercise 5: dynamic unipedal squat.

Participants had to rate the exercise effort between 12 and 18 on a 20-point Borg scale, which is considered necessary for training strength.[20] Based on the results of the pilot study, the same elastic bands were used for all men (red) and for all women (yellow). Participants recruited for the pilot study were not involved in the actual study because of habituation.

Signal Processing and Data Analysis

The MyoResearch 3.4 software (Noraxon, USA, Inc) was used for signal processing. Raw EMG signals were electrocardiogram reduced, rectified, and smoothed (root mean square [RMS], window = 100 ms). Resting EMG activity was considered baseline activity. For the MVICs,

Table 1. **Exercise Description**

No.	Exercise	Description
	Bilateral elevation with external rotation	All 5 exercise variations are performed with the participant standing with the feet shoulder-width apart and pointing forward. Both upper arms are aligned with the trunk, elbows flexed to 90°, and in neutral forearm rotation. Hands are shoulder-width apart and holding an elastic band with standard resistance to external rotation. The participant performs bilateral elevation to 90° while maintaining the external-rotation resistance.
1	Open hand	The participant stands on both legs with full knee extension. Head, trunk, and legs are vertically aligned. The ends of the elastic band are tied in a knot. The thumbs of both hands face upward, and the other fingers are extended. The elastic band is placed between the thumb and other fingers of both hands.
2	Closed hand	The participant stands on both legs with full knee extension. Head, trunk, and legs are vertically aligned. The participant makes a fist with both hands (all fingers flexed with the thumb on top). The elastic band is held in both hands (ends are loose).
3	Dynamic bipedal squat	The participant stands in a bipedal squat position with both hips flexed to 90° and both knees flexed to 60°. Head and trunk are aligned. The ends of the elastic band are tied in a knot. The thumbs of both hands face upward, and the other fingers are extended. The elastic band is placed between the thumb and other fingers of both hands. The participant extends the hips, knees, and trunk while performing bilateral arm elevation.
4	Static unipedal squat	The participant stands on the contralateral leg with the knee flexed to 30°. Head and trunk are vertically aligned. The ends of the elastic band are tied in a knot. The thumbs of both hands face upward, and the other fingers are extended. The elastic band is placed between the thumb and other fingers of both hands. The participant performs bilateral arm elevation while maintaining unipedal balance.
5	Dynamic unipedal squat	The participant stands on the contralateral leg with the knee flexed to 30°. Head, trunk, and legs are vertically aligned. The ends of the elastic band are tied in a knot. The thumbs of both hands face upward, and the other fingers are extended. The elastic band is placed between the thumb and other fingers of both hands. The participant extends the knee of the contralateral leg while performing bilateral arm elevation.

the mean EMG activity of the 3-second interval after the marker was used for further analysis. The marker was set to the time point at which maximal effort was achieved. All data were visually inspected, and the marker was manually reset when the interval did not contain the greatest EMG activity. The normalization reference level for each of the scapular muscles was considered the maximal activity generated across the 4 MVIC tests.[17] For the exercises, the analysis of marker motion identified the start and end of each repetition. Data from the first and last repetitions were not analyzed to avoid the influences of learning and fatigue. Mean EMG activity for every muscle was calculated across the 3 intermediate repetitions (18 seconds) for all exercises. Those values were then normalized according to the MVIC method and expressed as a percentage of MVIC for further analysis.

Selecting appropriate exercises to restore the intramuscular balances of UT : MT, UT : LT, and UT : SA is important from a clinical point of view.[5,6] Therefore, scapular muscle ratios were calculated by dividing the normalized EMG activity of the UT by the MT (UT : MT ratio), the LT (UT : LT ratio), or the SA (UT : SA ratio).

Table 2. **Electromyographic Activity of Each Muscle for the 5 Exercise Variations**

	Percentage of Maximal Voluntary Isometric Contraction, Mean ± SD			
Exercise	Upper Trapezius	Middle Trapezius	Lower Trapezius	Serratus Anterior
1	10.68 ± 6.92	17.13 ± 8.64	34.26 ± 17.96	20.37 ± 8.69
2	9.88 ± 6.72	13.60 ± 8.31	26.50 ± 15.97	20.49 ± 7.61
3	14.28 ± 9.88	18.23 ± 10.10	31.72 ± 16.89	18.57 ± 9.86
4	13.80 ± 8.88	17.21 ± 9.34	33.84 ± 16.75	22.90 ± 13.85
5	15.73 ± 9.06	16.84 ± 9.34	29.36 ± 13.61	18.22 ± 8.71

Statistical Analysis

We used SPSS (version 25; IBM Corp, Armonk, NY) to perform all statistical analyses. The MVIC trial-to-trial reliability for each separate muscle was calculated using intraclass correlation coefficients (ICCs; 2-way random model, type consistency). Means and standard deviations (SDs) were determined for normalized EMG values for each muscle and each exercise (Table 2). Based on the outcome of the Shapiro-Wilk test and visual inspection (histogram), we determined the data were not normally distributed. For each muscle, a linear mixed-model analysis with random effects for participants and the fixed factor of exercise was conducted to identify statistical differences in mean muscle EMG activity among the 5 exercises. The α level was set at .05. Post hoc pairwise comparisons were performed using the Bonferroni correction for multiple comparisons. Additionally, means and SDs were determined for all α values (Table 3). To determine differences for each ratio between exercises, we applied the same linear mixed-model analysis.

RESULTS

The ICCs for the 3 MVIC trials were 0.975 ($F = 39.23$, $P < .001$) for the UT, 0.980 ($F = 51.15$, $P < .001$) for the MT, 0.965 ($F = 28.39$, $P < .001$) for the LT, and 0.987 ($F = 79.74$, $P < .001$) for the SA. The mean EMG activity of each muscle and across exercises, expressed as a percentage of MVIC, is provided in Table 2. For all selected muscles, the linear mixed-model analysis showed significant results (all P values $\leq .001$). Post hoc analysis revealed that, for the UT, exercises 1 and 2 produced less activity than exercises 3, 4, and 5 (all P values $< .001$, except for exercise 1 versus exercise 4, $P = .017$). Mean differences with 95% confidence intervals (CIs) between exercise 1 and exercises 3, 4, and 5 were –3.67% MVIC

Table 3. Scapular Muscle Ratios for the 5 Exercise Variations

	Scapular Muscle Ratio, Mean ± SD		
Exercise	Upper Trapezius : Middle Trapezius	Upper Trapezius : Lower Trapezius	Upper Trapezius : Serratus Anterior
1	0.71 ± 0.45	0.45 ± 0.49	0.55 ± 0.31
2	0.87 ± 0.61	0.71 ± 1.14	0.48 ± 0.30
3	0.93 ± 0.62	0.68 ± 0.75	0.85 ± 0.52
4	0.92 ± 0.54	0.57 ± 0.55	0.69 ± 0.43
5	1.08 ± 0.62	0.75 ± 0.81	0.97 ± 0.55

(–6.02%, –1.33%), –2.68% MVIC (–5.06%, –0.29%), and –5.021% MVIC (–7.34%, –2.70%), respectively. Mean differences (95% CIs) between exercise 2 and exercises 3, 4, and 5 were –4.78% MVIC (–7.15%, –2.40%), –3.779% MVIC (–6.18%, –1.38%), and –6.13% MVIC (–8.48%, –3.78%), respectively. The MT was less activated during exercise 2 compared with exercises 1, 3, 4, and 5 ($P = .005$, $P < .001$, $P = .002$, and $P = .009$, respectively) with mean differences (95% CIs) of –3.44% MVIC (–6.19%, –0.68%), –4.63% MVIC (–7.36%, –1.90%), –3.60% MVIC (–6.33%, –0.88%), and –3.24% MVIC (–5.96%, –0.51%), respectively. For the LT, exercise 2 demonstrated less activity than exercises 1, 3, and 4 ($P < .001$, $P = .007$, and $P < .001$, respectively) with mean differences (95% CIs) of –7.76% MVIC (–12.05%, –3.47%), –5.22% MVIC (–9.51%, –0.93%), and –7.34% MVIC (–11.63%, –3.05%), respectively. Additionally, less LT activity was present during exercise 5 compared with exercises 1 and 4 ($P = .014$ and $P = .034$, respectively) with mean differences (95% CIs) of –4.90% MVIC (–9.19%, –0.61%) and –4.47% MVIC (–8.77%, –0.19%), respectively. The SA was more activated during exercise 4 than during exercises 3 and 5 ($P = .002$ and $P = .001$, respectively) with mean differences (95% CIs) of 4.32% MVIC (1.06%, 7.60%) and 4.68% MVIC (1.41%, 7.94%), respectively.

For all selected muscle ratios, the linear mixed-model analysis indicated significant results (P values $<.001$ for UT : MT and UT : SA and $P = .015$ for UT : LT). Post hoc analysis revealed that the UT : MT ratio was lower during exercise 1 compared with exercises 3, 4, and 5 ($P = .004$, $P = .039$, and $P < .001$, respectively). Also, the UT : MT ratios during exercises 2 and 4 were less than in exercise 5 ($P = .002$ and $P = .013$, respectively). Furthermore, the UT : LT ratio was smallest overall during exercise 1 and was different from exercise 5 ($P = .022$). Finally, a lower UT : SA ratio was present during exercise 1 versus exercises 3 and 5 (both P values $<.001$), exercise 4 versus exercise 5 ($P < .001$), and exercise 2 versus exercises 3, 4, and 5 ($P < .001$, $P = .017$, and $P < .001$, respectively).

DISCUSSION

This is the first study, to our knowledge, to investigate scapular muscle activity during 5 kinetic chain variations of a bilateral elevation with external rotation. Our main finding was that scapular muscle activity differed among the variations. More specifically, altering the upper extremity position (ie, hands closed instead of open) resulted in less MT and LT activity without changing the UT : MT and UT : LT ratios. Also, incorporation of the lower extremity had an effect on UT activity only, with greater EMG activity and increased ratios (except for UT : LT in exercises 3 and 4 and UT : SA in exercise 4). Moreover, LT activity decreased when a dynamic unipedal squat was added to the exercise. The greatest SA activity occurred when performing the exercise in a static unipedal squat position. We will address the results and make suggestions for rehabilitation exercises by focusing on goals (ie, increasing or decreasing activity in the scapular muscles) and not in light of the so-called best exercise because treatment and thus exercise selection should be tailored to every patient.

To investigate the effect of altering upper extremity position (ie, open or closed hand), exercises 1 (open hand) and 2 (closed hand) were compared. The UT and SA activity did not change between exercises, whereas MT and LT activity increased when the hands were open instead of closed. Despite small mean differences between exercises, these results suggest that an open-hand position is preferable to a closed position when more scapular retractor muscle activity is desired. A possible explanation is related to myofascial connections.[21] With an open-hand position, the superficial posterior myofascial chain could be activated, stimulating the forearm extensor muscle group, tightening the lateral intermuscular septum, activating the deltoid muscle, and thus leading to greater MT and LT activity. With closed hands, a superficial anterior myofascial chain might be activated. This activates the forearm flexor muscle groups, leading to tightening of the medial intermuscular septum and activation of the larger superficial glenohumeral muscles, such as the pectoralis major and latissimus dorsi. It would be interesting to investigate the roles of these muscles in future research. The deeper SA may not be influenced by hand position because this muscle is not part of any superficial myofascial connection. It is difficult to compare our results with those of others when different hand positions during elevation exercises have not yet been researched. Only Castelein et al[8] studied bilateral elevation with external rotation with closed hands in a comparable manner. Similar muscle activity levels were found for all scapular muscles: 9.9% versus 12.0% MVIC for the UT, 13.6% versus 19.1% MVIC for the MT, 26.5% versus 22.5% MVIC for the LT, and 20.5% versus 22.5% MVIC for the SA. Additionally, Henning et al[22] assessed scapular muscle activity while activating the kinetic chain using a functional throwing or holding (ie, throwing without ball-release) exercise. They did not report any differences in UT, MT, LT, or SA activity between throws (hand opens for ball release) or holds (hand stays closed). The 1-handed throwing or holding exercise may require more scapular stability than the bilateral elevation in our study, which could also be reflected in the higher muscle activity levels.

In view of the clinical purpose to decrease the UT : MT, UT : LT, and UT : SA muscle ratios in patients with shoulder pain and a hyperactive UT, all of the exercises we tested could be selected because all ratios were below or nearly equal to 1, meaning that the muscle activity of the UT was lower than or equal to that of the MT, LT, or SA. When we looked at the differences in muscle ratios during the exercises with varied hand positions, all were increased, although nonsignificantly, which could be taken into account when selecting exercises for restoring intramuscular balance.

With the incorporation of the lower extremity, exercise 1 was compared with exercises 3, 4, and 5. Only UT activity increased, suggesting that incorporation of the lower extremity is only beneficial when more UT activity is desired in rehabilitation, as proposed by some authors.[23,24] Mean differences between exercises ranged from 2.68% to 5.02% MVIC.

Concerning LT activity, De Mey et al[11] showed no difference when a retraction exercise (ie, low row) was performed in a bipedal standing position compared with a static or dynamic bipedal squat, which is in line with our results. In the same study, UT activity was not influenced by lower extremity position or movement, and LT activity did not change when a dynamic unipedal squat was added, which is in contrast to our results. This could be explained by the different exercises studied (external rotation with elevation in this study versus the low row in De Mey et al[11]).

For SA muscle activity, the largest difference was not associated with involvement of the lower extremity but rather between various types of lower extremity involvement. The SA activity was highest when elevation was performed in a static unipedal squat position, which was greater than performance in a dynamic bipedal or unipedal squat. Similar to the findings of Maenhout et al,[12] this could be explained by myofascial connections with the SA being part of an anterior-flexion chain.[21] During a unipedal static squat, the contralateral hip is flexed, which could activate the anterior hip muscles and consequently the contralateral internal oblique muscle, extending into the ipsilateral external oblique muscle and resulting in more SA activity. During a dynamic performance of the exercise, hip flexion and extension are alternated, which leads to alternating activation of the anterior and posterior chains, which may "level out" the effect on SA muscle activity. A similar interpretation could be applied when comparing exercise 1 with exercise 4: greater, although nonsignificant, SA activity occurred during exercise 4.

Incorporating the lower limb into an elevation exercise increased all scapular muscle ratios except for UT : LT and UT : SA in exercise 4 and UT : LT in exercise 3. These results suggest that lower extremity incorporation was not preferred over no incorporation for intermuscular ratios, but if activating the lower limbs is of interest, a static unipedal squat is the most favorable choice for scapular muscle balance.

Overall, lower extremity activation during an elevation exercise only increased activity in the UT, generally leading to increased scapular muscles ratios. Additionally, LT activity decreased when a dynamic unipedal squat was added (mean difference = 4.90% MVIC). Nevertheless, incorporation of the lower limbs into shoulder rehabilitation could be of benefit for an overhead athlete population with regard to exercise variations in the more complex kinetic chain.

As for the main study limitation, 3-dimensional kinematic data were not collected during exercise performance. Future researchers could pursue additional information on the relationship between joint kinematics and neuromuscular factors. Also, although our study contributes to the literature on exercise selection for scapular rehabilitation, the effect of scapular muscle training with incorporation of the kinetic chain has not yet been investigated. Therefore, kinetic chain training compared with traditional training for athletes with scapular dysfunction should be the focus of future investigators. Additionally, this work was performed on healthy, young participants (average age = 22.48 years), so generalizing our results to an older population or patients with shoulder conditions should be done with caution. Older adults (average age = 71.1 years) have shown greater UT and MT activity during loaded elevation than young adults (average age = 25.0 years).[25] Nevertheless, when participants with or without shoulder conditions were compared, scapular muscle activity was similar during unloaded multijoint functional exercises.[26] Furthermore, scapular muscle activity in our study was generally low because all exercise variations were low load. So in light of this, the relative differences between exercises were rather small. Also, we did not consciously control scapular position, which may have influenced scapular muscle activity during elevation exercises in overhead athletes with subacromial impingement.[27] Another limitation is inherent to the use of surface EMG during dynamic exercises. Nevertheless, standard guidelines were strictly followed.[16]

CONCLUSIONS

In clinical practice, the influence of the kinetic chain on scapular muscle activity should be taken into account when selecting appropriate elevation exercises. Performing a bilateral elevation with external rotation using an open hand instead of a closed one is more beneficial when higher scapular muscle activity is desired in rehabilitation. Overall, lower extremity incorporation did not increase scapular muscle activity except for the UT, and it is recommended only to achieve more UT activity during exercising. For scapular muscle balance, incorporating variations in the kinetic chain is not preferred. However, kinetic chain involvement in shoulder rehabilitation exercises could be helpful for overhead athletes with regard to exercise variations in the more complex kinetic chain.

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REFERENCES

1. Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. *Clin Sports Med*. 2013;32(4):637–651.
2. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part III: the SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19(6):641–661.
3. Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: new concepts on throwing mechanics and injury. *PM R*. 2016;8(suppl 3):S69–S77.
4. Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. *Br J Sports Med*. 2014;48(8):692–697.
5. Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. *BMC Musculoskeletal Disord*. 2010;11:45.

6. Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports*. 2007;17(1):25–33.
7. Wright AA, Hegedus EJ, Tarara DT, Ray SC, Dischiavi SL. Exercise prescription for overhead athletes with shoulder pathology: a systematic review with best evidence synthesis. *Br J Sports Med*. 2018;52(4):231–237.
8. Castelein B, Cagnie B, Parlevliet T, Cools A. Superficial and deep scapulothoracic muscle electromyographic activity during elevation exercises in the scapular plane. *J Orthop Sports Phys Ther*. 2016;46(3):184–193.
9. Brumitt J, Dale RB. Integrating shoulder and core exercises when rehabilitating athletes performing overhead activities. *N Am J Sports Phys Ther*. 2009;4(3):132–138.
10. Wilk KE, Arrigo CA, Hooks TR, Andrews JR. Rehabilitation of the overhead throwing athlete: there is more to it than just external rotation/internal rotation strengthening. *PM R*. 2016;8(suppl 3):S78–S90.
11. De Mey K, Danneels L, Cagnie B, Van den Bosch L, Flier J, Cools AM. Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes. *J Sci Med Sport*. 2013;16(1):65–70.
12. Maenhout A, Van Praet K, Pizzi L, Van Herzeele M, Cools A. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? *Br J Sports Med*. 2010;44(14):1010–1015.
13. Nagai K, Tateuchi H, Takashima S, et al. Effects of trunk rotation on scapular kinematics and muscle activity during humeral elevation. *J Electromyogr Kinesiol*. 2013;23(3):679–687.
14. Vega Toro AS, Cools AM, de Oliveira AS. Instruction and feedback for conscious contraction of the abdominal muscles increases the scapular muscles activation during shoulder exercises. *Man Ther*. 2016;25:11–18.
15. Yamauchi T, Hasegawa S, Matsumura A, Nakamura M, Ibuki S, Ichihashi N. The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics. *J Shoulder Elbow Surg*. 2015;24(6):955–964.
16. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361–374.
17. Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal normalization tests for muscle activation of the levator scapulae, pectoralis minor, and rhomboid major: an electromyography study using maximum voluntary isometric contractions. *Arch Phys Med Rehabil*. 2015;96(10):1820–1827.
18. Borms D, Ackerman I, Smets P, Van den Berge G, Cools AM. Biceps disorder rehabilitation for the athlete: a continuum of moderate- to high-load exercises. *Am J Sports Med*. 2017;45(3):642–650.
19. Cools AM, Borms D, Cottens S, Himpe M, Meersdom S, Cagnie B. Rehabilitation exercises for athletes with biceps disorders and SLAP lesions: a continuum of exercises with increasing loads on the biceps. *Am J Sports Med*. 2014;42(6):1315–1322.
20. Andersen LL, Andersen CH, Mortensen OS, Poulsen OM, Bjrnlund IB, Zebis MK. Muscle activation and perceived loading during rehabilitation exercises: comparison of dumbbells and elastic resistance. *Phys Ther*. 2010;90(4):538–549.
21. Myers TW. *Anatomy Trains. Myofascial Meridians for Manual and Movement Therapists*. Edinburgh, Scotland: Churchill Livingstone; 2001.
22. Henning L, Plummer H, Oliver GD. Comparison of scapular muscle activations during three overhead throwing exercises. *Int J Sports Phys Ther*. 2016;11(1):108–114.
23. Mottram SL, Woledge RC, Morrissey D. Motion analysis study of a scapular orientation exercise and subjects' ability to learn the exercise. *Man Ther*. 2009;14(1):13–18.
24. Pizzari T, Wickham J, Balster S, Ganderton C, Watson L. Modifying a shrug exercise can facilitate the upward rotator muscles of the scapula. *Clin Biomech (Bristol, Avon)*. 2014;29(2):201–205.
25. Kim T, Kim M, Lee M, Yoon B. Comparison of scapular muscle activation during shoulder elevation in older and young adults: a pilot study. *J Back Musculoskelet Rehabil*. 2019;32(3):437–443.
26. Moeller CR, Bliven KC, Valier AR. Scapular muscle-activation ratios in patients with shoulder injuries during functional shoulder exercises. *J Athl Train*. 2014;49(3):345–355.
27. Huang TS, Du WY, Wang TG, et al. Progressive conscious control of scapular orientation with video feedback has improvement in muscle balance ratio in patients with scapular dyskinesis: a randomized controlled trial. *J Shoulder Elbow Surg*. 2018;27(8):1407–1414.

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